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I. INTRODUCTION

A modern metropolitan hospital, perhaps more than any other social institution, is dependent upon rapid and accurate information flow. Because, in the practice of modern medicine, correct information at the right time can be vital to save a life or prevent a catastrophe, the hospital is increasingly vulnerable to failures in the information net. Yet relatively little has been done to modernize medical information-handling procedures. Although the amount of information is burgeoning in parallel with medical-science research, interest in reliable, automated medical-information processing has only recently begun to grow.

Evolving social institutions relating to the delivery of medical care, urbanization of medical services, and increasing population have made medical data management a critical problem. Historically, organized medical-information systems have been based upon manual methods of recording and transport. They have been adequate although incomplete,

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costly, burdensome, and slow. It has been generally estimated that, in an average hospital, the cost of patient record-keeping and information handling is on the order of $20 per patient-day. The national magnitude of this cost, using the National Center for Health Statistics' estimate of 500 million hospital patient-days annually, is $10 billion [1]. Even if we presume 100-percent error, the daily cost is $10, and the national cost still $5 billion. This leads us to consider whether use of computer-based automation to support, supplement, or replace the all-manual methods would not 1) reduce the cost per patient-day and simultaneously 2) improve patient management through more timely, complete, and accurate information.

Proponents of automated methods argue the swiftness, timeliness, lack of duplication, and availability of the record, as well as more sophisticated benefits such as automatic statistical and analytical transformations of the data, and access to comparison cases and reference material by the ward-level physician. Skeptics argue the high cost of the initial system, retraining of personnel, lack of demonstrable benefit, inadequacy of current systems, and such subtle points as lack of record privacy and legality. Although the outcome of this issue is not yet clear, it seems likely that we are now in a transition period. Reduction of computer costs, development of software systems, and invention of facile interface hardware will lead to highly organized, adequately cost-effective computer-based hospital information systems (HIS).

This Paper reviews the current status in this country of automated HIS, with particular emphasis on the involvement of the U.S. Public Health Service (Department of Health, Education, and Welfare) in the development and deployment of these systems. Systems are being designed or developed elsewhere in the world (particularly Scandanavia, England, and Japan), but we focus our attention on U.S. efforts.

The Public Health Service is immediately concerned with potential technological aids because of its responsibility to improve the delivery of health care services. A growing technology should have a profound effect on the service's future plans. Properly developed and introduced, automated systems could allow additional freedom and imagination for policy decisions. Improperly introduced into the health care community, they could be quite costly and have negligible or even adverse effects on policy.

In preparing this Paper, it was necessary to clarify the broad concept of HIS, and then describe subcategories in more detail. We briefly describe these subcategories and also attempt to summarize the degree of Federal involvement. However, a *caveat* is in order. It is obvious to even the most casual observer that this new field is chaotic. Developments are not yet coordinated via the literature and a total overview is difficult to obtain. Even the Federal Government does not have well organized information systems, nor does it have an information center for such activities. In consequence, any effort to summarize the field will necessarily be incomplete. This Paper gathered available data in the Public Health Service and from a search of the current literature. In addition we have looked briefly at industrial experience.

The category of HIS is quite broad; it includes all potentially automated information sources, data transformation and management requirements, and user information needs in a patient-management facility. These requirements originate in the several organizational elements of a medical center that include:

1) The medical staff,
2) The admitting procedure,
3) Medical record keeping,
4) The nursing units,

5) Diagnostic services (X-ray, etc.),
6) Treatment services (Radiology, etc.),
7) Hospital business and administration,
8) Hospital service operations (Pharmacy, etc.),
9) Communications (Reception, etc.).

Each of these elements originates and uses patient information [2]. Since patient information constitutes the kernel of the general problem of patient management, improvements in patient management should result from having more information more immediately available.

II. TECHNOLOGICAL CONSIDERATIONS

Technological developments applicable to the medical information problem have come, for the most part, from prior development and application in industry and the military. Computers are the primary tools for information systems, but, except for minor trends in research and patient monitoring, the computers in use are essentially identical to those used in non-medical applications. However, very recently, the pressing realization that medical systems are unique and complex has led to the evolution of specialized instruments and systems.

We must distinguish between the hardware and software of the information system; for medical application both will require considerable attention. The central hardware, a computer with a time-sharing system, is becoming fairly standard. However, the various peripheral terminals suitable for the numerous sub-environments of a medical institution are yet to be defined, despite several experiments (discussed below). Requirements at a nursing station differ from those at the admitting station or a clinical chemistry laboratory. If cost is not a major consideration, computer technology is equal to the task. In principle, when the several requirements are well known, remote terminals will be available. Cost, however, is a consideration, and therefore remote terminals are usually designed with less power than they need to do the job. In the future one may reasonably expect terminal cost to continue to decrease, and power to increase.

As for the software requirements, unfortunately, an applications program developed at one institution will generally not immediately run at another. However, the essential *idea* of a demonstrably useful program can be transferred, and the program either modified or rewritten. In this respect, software systems are similar to any other discipline, principles stand and libraries accumulate. In time, the operational essentials will be well known.

Nevertheless, medical system software must be evaluated on a deeper level. Several abortive designs have shown that a computer system configuration may function perfectly for an information task and yet be useless in the medical environment. Usually, this is because the special applications programs required for that environment have not yet become cost-effective or desirable for the problems and users at hand.

Because medically-oriented tasks are considerably more complex than was at first realized, users have become disillusioned with the magic promise of computer systems. The applications programs for medical data management, to say nothing of more sophisticated programs such as hypothesis testing and patient management, do require considerably more subtlety than those for, say, industrial inventory control. For example, a rather arbitrary distinction may be drawn between a system for handling patient data and one for generating patient information. The former gathers and distributes the raw result of assaying or measuring patient parameters and variables. The latter is a consequence of raw data transformation and analysis by either human or automatic means, and may involve judgmental data, or, say, statistical inference or modeling techniques. Presumably, information is considerably more useful than raw data because of its transformation, or its context, or perhaps, because of the exercise of rational inference. Automatic handling of patient data would certainly improve the efficiency and accuracy of data management, but an information system has the potential of contributing importantly to patient management. Although much, if not all, of the basic functional specifications for a hospital system may now be written, at this deeper level of patient-oriented programs, much research is still required.

The broad system for computer-based medical information management in a health care facility should properly be directed to the tasks of patient management, and therefore serve directly in the problems of patient care administration, diagnosis, prognosis, and therapy. However, it is clear that there are problems of collecting, storing, transforming, and displaying the basic data upon command. Consequently, efforts to design and implement data management systems have most frequently been specific task-oriented projects in which the data, as well as the task, have some chance of definition. Such specific information systems are, for example, directed to the following services:

1. Nursing Station
2. Admitting Office
3. Business Office
4. Historical Medical Records
5. Automated Service
   a. clinical chemistry
   b. pharmacy
   c. dietary service
   d. blood bank
   e. radiology
   f. operating rooms
   g. other
6. Current Patient Records
7. Outpatient Records
8. Epidemiology
9. Chronic Disease Records
10. Research Functions
11. Automated History
12. Continuing Education
13. Patient Management
    a. diagnosis
    b. optimum therapy
    c. planning
14. Statistical Services
15. Consulting Services
    a. emergency information
    b. library
    c. referral
16. Patient Monitoring
17. Emergency Services
18. Program Planning and Budgeting
19. Community Integration

Each of these services requires the development of the capacity to gather, manage, and display the data peculiar to that service--data as diverse as the services themselves. Thus, an automated hospital would not have *an* information system, but a *conglomeration* of relatively discrete information sub-systems. Presumably, these would then be integrated into a smooth, centralized, information-handling capability able to correlate and collate as much information from each sub-system as necessary to provide a comprehensive medical and/or administrative picture.

A TOTAL HOSPITAL INFORMATION SYSTEM

A total hospital information system is a computer-based communication system capable of providing requisite data management for every major medical and administrative service in the hospital. At minimum, it must be able to gather, store, and retrieve data pertinent to that service, retrieve and display pertinent data gathered at other services, and perhaps communicate with specialized data banks elsewhere ~~(for example, with the veteran's service or with Medicare).~~ However, a truly successful and useful HIS must do much more with the data: conversion, transformation, statistical analysis, normalization, at least rudimentary model building and hypothesis testing (rules-of-thumb, etc), and comparison with or retrieval of reference material from the historical medical records or the reference library (for example, the poison files or tables, graphs, or rules for acid-base and fluid therapy). Ideally, such a system should be able to support much more complex procedures in patient management, for example, automatic construction of simulations of the patient state for trial therapy, support of physician decision using statistical decision trees, and patient monitoring and screening. However, these latter procedures are beyond the scope of this Paper.

Primarily, a HIS will contain the patient record, and must therefore acquire, organize, and retrieve these data on command. Current records are probably best kept in high-speed memory banks in the central computer so that they can be recalled or updated from remote terminals within a reasonably short time [3]. The main computer would also contain particular programs relating to particular activities at the remote terminals. Specialized terminals would be distinguished not only by the hardware appropriate to the local function, but also by the programs accessed to process data. For example, the business office terminals are likely to continue to be small, peripheral computers that acquire current patient data from the central computer, update business records, predict room occupancy from nursing unit terminals, maintain inventory from the pharmacy, and perform billing operations [4].

The admitting office terminal, using current technology, would be an interactive device with which the patient converses. It would enter the interview data, order tests, and schedule and make room assignments. After the patient has answered a thorough and self-checking list of questions for the initial medical record, an initial problem list, determined tentatively by a computer, could be provided for the physician [5].

The nursing station terminal is considerably more complicated, to accommodate the several activities there. It is likely to be an interactive console incorporating a CRT display and having various input devices. The nurse or clerk enters current information either by typewriter, multiple-choice answers using a form of stylus, or by monitoring devices and automatic transcription. Several terminals designed for aspects of this job have been demonstrated experimentally [6]. These terminals must also communicate physician orders to the pharmacy, laboratory, business office or similar services. More research is needed on such problems as facile acquisition of nurses and doctors' notes and complete physician summary, sufficiently flexible display, and, in general, those problems directly related to the man-machine interface.

The automated chemistry laboratory currently only punches cards or writes tapes that are then carried to the computer [7], but it is not a great step to insert the data automatically into the patient record for recall at the nursing station. The automation design for each laboratory service will naturally be different. Entry of pictorial data (X-ray, etc.) is as yet an unsolved problem, whereas the pharmacy orders and inventory control can be worked out in a variety of ways. A feasible automation of the pharmacy has been achieved at the University of Southern California, in Los Angeles County General Hospital [8].

Epidemiology, statistical services, research, and program planning terminals now exist in a variety of forms, but for the most part these services currently use "batch" processing. The near future will bring "interactive" terminals whereby a user may share the computer with others via a remote terminal, scanning and analyzing banks of data essentially in a conversational mode with the computer. More sophisticated problems include interactive terminals used in support of physician decisions, as diagnostic and therapeutic aids, in clinical patient management, or for continuing or undergraduate education. All these uses seem possible in principle, but are quite difficult in actuality.

Despite these possibilities for the future, we must repeat the *caveat* that although feasibility may have been demonstrated in a variety of cases, these are generally far from a working, acceptable total system. The systems are already very useful in some cases, such as out-patient scheduling, automated pharmacy, clinical chemistry, and a few others; in most instances, however, research and development is still required to make such systems cost-effective and useful in the medical environment. Nowhere does a complete system exist, but pieces certainly do, and reasonable predictions may be made so long as we are careful not to impose a strict time deadline.

IV. BACKGROUND AND DATA SUMMARY

Our objectives in this Paper were to 1) give a broad view of the components of an automated HIS, 2) briefly evaluate the cost and utility of current systems, and 3) estimate their future importance.

In collecting data, it became evident that there would be classification problems. First, the numerous ramifications of an HIS program and the interest of many Federal agencies in similar or related systems made it inefficient if not inappropriate to attempt a government-wide catalogue of funded projects. Information was cross-checked on several lists, such as the *Research Grants Index* and a number of grants lists prepared by the respective granting agencies [9-24]. A second problem, involving arbitrary decisions, was to determine which projects were truly relevant. Obviously, computer-based research projects such as a statistical diagnostic program are relevant, but not directly, and we chose to refer only to those projects concerned with communication or information gathering and data management within the hospital. Frequently, too, actual information detailing each project is ambiguous. For example, the information supplied may give categories in which the investigators aspired to do research as well as categories in which they actually engaged in research. Again, if the researcher is working in several areas simultaneously, it is difficult to determine the priorities he has placed on these several areas. There is, therefore, an uncertainty in conclusions drawn about funds expended or areas emphasized.

A complete report is not currently available from the Department of Defense relative to funds expended by that department for HIS research and development. There are several projects, but rather than conjecture, these data sources are not included in this Paper. The Army, Navy, and Air Force all have significant programs in this area;

but their expenditures are considerably less than in the DHEW. However, the Veterans Administration has devoted approximately $6 million to the development of a total HIS, and considerable work is currently underway. Of course, the Veterans hospitals would greatly benefit by an automated network of information systems [25-27].

Two significant non-Federal sources of research and development funds for HIS must also be noted. The first is speculative private industry; TRW, MITRE, North American, Aerospace, and others have developed certain aspects of information systems, some of which are directed particularly to the medical environment. The Systems Development Corporation, Bolt Barenek and Newman, Lockheed Corporation, and National Data Communications Corporation, among others, also have programs devoted to the development of a total HIS. This is a reasonably heavy commitment, but the total expenditure is unknown.

For private industry, this field appears to be potentially quite lucrative. Unfortunately, it is not possible to directly transfer technical knowledge and developments available from industrial or military application, and the process of adaptation to the medical environment is exceptionally difficult for a variety of reasons. Development appears to be quite expensive in time and equipment. A reasonable estimate to bring up a minimally functioning total HIS is currently 200 experienced man-years. This figure will, of course, vary considerably; in particular, it will go down as non-fragile, applicable hardware and software sub-systems are developed and become available in the literature and program libraries.

The second important non-Federal source is self-sponsored work in patient-care institutions. Total expenditures related to computers can be estimated from the number of computer installations in hospitals. Questionnaires were mailed to 2431 hospitals [28]. Of the 1251 responders, 543 used computers in some form, primarily in business applications. Assuming that the sample is representative, and extrapolating, we can infer that at least 1500 of the 2431 used computers. Of the 708 responding non-users, 129 planned to install computers within 12 months. Based on the data of the questionnaire, it may be estimated that private sources furnish a considerable amount of computer funds. The fraction devoted to research and development cannot be estimated from available data but must be small, say, less than ten percent. This rough estimate of hospital computer usage can furnish planning information regarding the potential market even if it cannot be interpreted in terms of present R&D support.

SUBCATEGORIES OF HIS*

In searching the Federal grants and contracts for data accumulation and analysis, it became apparent that actual current research and development is being done in six major categories of HIS:

1) Medical records,
2) Business office transactions,
3) Logistics,
4) Diagnostic laboratory services,
5) Physiological monitoring,
6) Total hospital information systems.

Medical Records

Subsumed under this category are three major activities important in the development of HIS: medical record-keeping; filing and retrieving orders, notes, and observations of the medical staff; and the rudimentary library reference function.

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*Sources of data for the following summaries are from Public Health Service agencies only.

The medical record, normal commentary of the staff, and related data are the central objects of the data management system (aside from the accounting and business office functions). In principle, it would seem relatively straightforward to record and recall these data; in practice, the process is considerably more exacting. The system must store and retrieve formalized as well as textual information streams, numerical as well as pictorial or analog data. The sheer volume of material is, on the average, very high per patient since reports from several services, the complete history, and daily charts and summaries are in the record. Also, the input interface must be smooth and direct. For example, should the physician entering reports and orders deal directly with the computer interface or dictate for entry by a clerk? And how does he verify that his orders are correctly transcribed? Converse problems apply upon retrieval and display of the data. Finally, there are problems of encoding, of allowable vocabulary and nomenclature, of efficient file structures, of statistical analysis, privacy, and cost, to say nothing of the unique culture of the medical community into which the technology must smoothly intrude. Nonetheless, these tasks are tractable and adequate systems will develop. Since 1962 the PHS has obligated approximately $4.5 million for such development [29-32].

Business Office Transactions

Included in this category are such activities as payroll, billing procedures, accounting, and personal operations. These procedures are generally the simplest for the hospital to accomplish, primarily because such transactions are similar to other computer-programmed systems and constitute standard operating procedures. Hospitals usually automate this category first. About three times as many hospitals report using a computer for business office transactions than for any other use.

There is only one government-funded project that could fairly be listed under this category; it is a demonstration of a shared hospital data system [33]. In this application, a time-sharing system was demonstrated in which ten hospitals shared a computer for business office data processing. One could say, however, that an "all or none" situation is operating in selecting from government-funded projects for this category. That is, all qualify because of an expected spin-off to patient care. On the other hand, none qualify because the major purposes for which the project was funded were in all instances representative of a patient care management function. In sum, perhaps $2 million has been spent by the PHS in the development of business office records.

Logistics

Under this category are the several departmental inventory control and distribution systems. These include, among others, the pharmacy, dietary, central supply, and the laundry services. Again, inventory control and distribution of supplies and equipment are computer functions well worked out by industry, although the medical environment imposes special requirements. A combination of industrial engineering and systems analysis techniques are usually used to develop an optimal system.

To date, the majority of hospitals simply maintain depots on the nursing unit for each of these departmental supplies. Freisen [34] has been developing a decentralized concept for distributing supplies to the nursing unit, removing the centralized depot on the unit, and establishing an area in the patient room to store equipment for use. Also, the Freisen concept centralizes the storage area for all equipment and supplies for the hospital in a large receiving, storage, and processing area so that distribution to the several rooms in anticipation of demand requires careful and detailed planning.

In addition to the inventory problem, the pharmacists have also been concerned with automatic drug distribution systems. An appropriate solution, unit doses individually packaged and automatically dispensed, has been suggested, but is difficult to implement. For instance, an appropriate dispensing device for the nursing station, ward, or room, needs to be developed that would be controlled by the central information system. Problems in menu allocation and dietary scheduling are also under study [35-38].

Finally, attempts are being made to develop efficient schedules for out-patients, ambulatory clinic patients, patient admission and interview, and bed utilization. Certain of these queueing programs are in operation [39-41].

Approximately $4.25 million has been obligated in this category by the PHS.

Diagnostic Laboratory

Under this category are included the clinical laboratory, radiology, and multiphasic screening. Their common central activity of furnishing diagnostic information also implies a data-handling function and a logistics function. The total PHS involvement to date is about $5 million [42-52]. For the X-ray department the computer may, in the future, provide assistance in reading the X-rays. Currently, however, its functions are preparing the reports, scheduling, and automating the treatment protocol. Although these latter activities are fairly common, the former, automated image analysis, has proved to be a surprisingly refractory problem.

In multiphasic screening, the computer can assist in patient scheduling, monitoring some of the tests, data recording and analysis, initiating and supplementing patient records, and decisionmaking. Collen [51] is representative of the PHS activity in this area where the current emphasis, in addition to developing the screening process itself, is in automation of data recording and analysis.

Automation of the clinical chemistry laboratories began with automatic analytic equipment. Subsequently, in a natural progression, results were automatically punched in computer-readable format, and finally read directly into a computer system where results may be transmitted to the ward. Demonstrations of feasibility for such data acquisition, transmission, and retrieval have considerably changed the complexion of future chemical laboratories even though the automatic equipment has by no means reached a state of final development. Refinement of the equipment and procedures will continue, but already the ready source of analytic data has spurred research efforts and resulted in a better understanding of population statistics [53]. Efforts are now underway to automatically incorporate the patient data into rudimentary mathematical models of blood and whole body chemistry for studies in acid-base physiology.

Table 1 is a current list of computerized clinical laboratories. Table 2 was compiled by Berkeley Scientific Laboratories and describes certain installations in somewhat more detail.

Physiological Monitoring

Included in this category are programs for the development of coronary care units, intensive care or critical care units, and operating room and cardiac catheterization laboratories. There are at least four distinct functions of physiological monitoring to be considered: detecting, recording, automatic analysis, and display of certain physiological signals and patient information. Early developments in this field took the view that the system was to be an early-warning device to detect and call attention to anomolies or dangerous trends. A more current view is that

Table 1

COMPUTERIZED CLINICAL LABORATORIES

Institution	Status: In Development	Status: In Operation	Off-Line: Non-Computer Data Acquisition System	On-Line: Small Computer Systems	On-Line: Medium Computer Systems	On-Line: Medium-Large Computer Systems	On-Line: Small Computers Linked to Large Computers
University of Tennessee		X	IBM 1080				
Firestone Hospital (Akron, O.)		X	IBM 1080				
~~Notre Dame Hospital~~ (Montreal)		~~X~~	~~IBM 1080~~	~~IBM 1130~~			
Youngstown		X	IBM 1080		IBM 360/30		
Clinical Lab Group (Los Angeles)		X	IBM 1080	IBM 1130			
Methodist Hospital (Brooklyn)		X		PDP8/S			
New England Priv. Res. Cntr.		X		PDP8/S			
Wake Forest		X		PDP8/S			
University of Virginia				PDP8			
Mason Clinic (Seattle)		X		PDP8			
Lab Procedures/Upjohn Corp. (Culver City, Ca.)		X		PDP8			360 Compatible
Kaiser Permanente (S.F.-Oakland)		X		AUTOCHEMI			PDP8 360/50
Biosciences Laboratories (L.A.)		X		LINC8			
Duke University (Durham, (N.C.)		X		2-LINC8's			
University of Wisconsin		X		LINC8			
University of California Med. Cntr. (San Francisco)		X		BSL			
Perth Amboy		X		SPEAR-LINC			
University of Colorado		X			IBM 1800		
University of Kentucky		X			IBM 1800		
University of Washington	X				IBM 1800		
King County Med Labs (Seattle)		X			IBM 1800		
Presbyterian St. Luke's (Chicago)		X		BSL (CLINDATA SYSTEMS, except where indicated)			
St. Vincent Hospital (Portland)		X		BSL			
Kaiser Hospital (Honolulu)		X		BSL			
Kaiser Hospital (Hollywood)	X			BSL (CHEMDATA SYSTEM - 16 AA CHANNELS)			
NIH (Bethesda, Md.)		X		BSL			
Upjohn Co. (Kalamazoo, Mich.)		X		BSL			
USPHS (Baltimore, Md.)	X			BSL			
University of British Columbia		X			PDP9		
Latter Day Saints Hospital (Salt Lake City)		X				CDC 3200 3300	
University of Minnesota	X					CDC 3200	
NIH (Bethesda, Md.)		X				CDC 3200	
University of Kansas	X	(Development not yet underway)				SDS SIGMA 5	
University of Alberta	X						PDP8--360/65
University of Missouri		X		IBM 1440			
Veteran's Admin. (L.A.)		X	IBM 1401				
Army Nutrit. Center (Fitzsimmons Army Hospital, Colo.)	X		IFOTRONICS	PDP8/S			
City of Memphis Hospital		X	IBM 1080		IBM 360/40		
Yale New Haven		X	IBM 1130				
Sutter Commun. & Gen. Hospital (Sacramento, Ca.)		X		SPEAR-LINC			
Methodist Hospital of Brooklyn		X		PDP8			

Table 2

AUTOMATED CHEMICAL LABORATORY FACILITIES

Place	Subject	Type of Automation	Computer
Bio-Science Laboratories Los Angeles Dr. R. H. Henry Dr. G. Kessler	Organization of a large commercial laboratory.	AutoAnalyzers on-line to IBM 1800.	Cards punched with results a) from manual tests by keypunching and b) from AutoAnalyzers by IBM 1800 on-line. All cards then fed to IBM 1400 computer for billing and records.
School of Medicine, University of California, Los Angeles Mr. W. S. Russell Prof. P. Sturgeon	Use of data processing in clinical chemistry and surgical histology. Use of continuous flow techniques in hematology.	Use of the AutoAnalyzer in serology.	IBM 360/75 installation to record surgical pathology findings. Routine storage and reporting of biochemical results.
Perth Amboy General Hospital, New Jersey Dr. H. C. Pribor & Dr. W. R. Kirkham Pathologists Mr. J. Foley & Dr. G. Fellows of the SPEAR Corp.	The use of the SPEAR Computer System in a laboratory serving a 550 bed general hospital, including the potential of the system for further development.	Technicon equipment: SMA-12 Survey Model and various AutoAnalyzer units in routine use: SMA-4 in use in hematology.	The partially developed SPEAR system. Some routine use of the computer, e.g., for protein electrophoresis calculations.
Section of Clinical Pathology, School of Medicine, Yale University, New Haven, Conn. Prof. D. Seligson	Laboratory automation and data processing.	A series of laboratory-built discrete analyzers all linked to one data logger.	Cards from the data logger processed in an IBM 1130 sited in the laboratory and operated by laboratory technicians.

Table 2--Continued

Place	Subject	Type of Automation	Computer
King's County Research Laboratories, Brooklyn, New York Mr. M. A. Blaivas Mr. A. Mencz	Organization of a large commercial laboratory receiving specimens by van delivery from practitioners and small hospitals from the New York area and by post from much of the USA and from other countries.	Multiple AutoAnalyzers on-line to a computer.	AutoAnalyzers on-line to an IBM 1710 computer. Replacement of this by an IBM 1800 data acquisition system was well advanced and an IBM 360/30 computer is then to be used for data processing and billing.
Division of Clinical Pathology and Laboratory Medicine, University of California, San Francisco Dr. G. Brecher Dr. O. Siggaard-Andersen	Use of PDP8 computer and Berkeley Scientific Laboratories (BSL) equipment in hematology and chemical laboratories.		Routine use of PDP8 and BSL laboratory data input consoles, mainly for hematology.
	Micro-analysis.	Several micro-techniques devised by Dr. Siggaard-Andersen	
Montreal, Prov. of Quebec, Canada Dr. M. Young (Toronto)	In-Patient and Out-Patient screening techniques.		
Mr. E. Whitehead, Technicon Instruments Corp.	Accuracy and precision of the SMA-12		

Table 2--Continued

Place	Subject	Type of Automation	Computer
Montreal (Cont.)			
Dr. G. Letellier Hospital Notre-Dame, Montreal	Specimen identification and off-line data processing.	SMA-12 coupled to IBM 1080 system.	Cards from IBM 1080 transmitted by IBM 1050 to IBM 1130 computer several miles away.
Clinical Pathology Dept. National Institutes of Health, Bethesda, Md. Dr. G. Z. Williams Dr. E. Cotlove Dr. D. Young Dr. T. Dutcher Dr. Marsh	Use of on-line computer facilities in laboratories. Laboratory organization. Accuracy and precision. Use of large laboratory computer. Specimen identification. Biochemical individuality. Development of an automatic enzyme analyzer. Automation of Bacteriology.	A six channel system of AutoAnalyzers on-line to a CDC 3200 computer. A patient-specimen identification system (not fully mechanized). A discrete enzyme analyzer based on the Gilford Recording Spectrophotometer. Experimental apparatus to log bacterial growth by turbidity for antibiotic testing.	Use of punched card requesting with computer output of worksheets and reports. Limited statistical evaluations of laboratory findings. Berkeley Scientific Labs Data Console used for input of hematological results to the computer. Use of paper or magnetic tape as buffer store.
Army Nutritional Center, Colorado		AutoAnalyzer on-line gas chromatograph on-line.	Infotronics and PDPS/8
Los Angeles County General Hospital Dr. A. G. Ware	Laboratory organization. Division of the laboratory into a) routine, b) emergency, and c) special investigation areas.	Prototype of a Beckman 4-channel discrete automatic.	

Table 2--Continued

Place	Subject	Type of Automation	Computer
San Francisco General Hospital Dr. M. Pollycove Dr. M. Fish	Laboratory organization. Projected use of PDP8 and B.S.L. equipment in chemical laboratories.	Laboratory on-line operation.	PDP8 and B.S.L. equipment delivered but not yet commissioned.
Berkeley Scientific Laboratory, Berkeley, Calif. Dr. H. Wattenburg		AutoAnalyzer recorder trace simulator.	Use of PDP8/S for signals on-line from AutoAnalyzers and connected to PDP8 like a B.S.L. console.
University of Colorado Medical School, Denver Dr. E. B. Reeve Dr. Aikawa	Use of computers in physiological measurements. Data processing in routine hospital laboratories.	Multiple and single-channel AutoAnalyzer on-line to IBM 1800.	Early stages of on-line data processing using IBM 1800.
Department of Clinical Pathology, Northside Hospital, Youngstown Hospitals Association, Ohio Dr. A. E. Rappoport Mr. W. Gennaro	Use of IBM 1080 system.	IBM 1080 Patient Identification system in use in certain areas of the laboratory.	IBM 1080 combined with a manual punching system. Results fed off-line to an IBM 1440 (the hospital's computer). IBM 105 duplicating cards fed in from Youngstown Southside Hospital.
Sutter Community & General Hospitals, Sacramento, Calif.	Laboratory data management.	AutoAnalyzers on-line.	Spear-Line Class 300.

Table 2--Continued

Place	Subject	Type of Automation	Computer
Permanente Medical Group Medical Methods Research, Oakland, California Dr. S. Ramcharan	Clinical and laboratory testing of ambulant population.	Specially built 8-channel AutoAnalyzer and various devices for rapid clinical measurements.	Signals from AutoAnalyzer converted to a result and punched automatically into cards. Anthropometric measurements also automatically punched into cards. Other data entered on cards by mark-sensing. All cards processed by IBM 360/40. IBM 2701 system receiving signals from cards read at a remote station and transmitting directly into the computer.

the automated system should do much more; in particular, it should do sufficient analysis of monitored variables, and sufficient transformation for display, to usefully support subsequent physician decision and action. That is not to say that the system will indicate the next step in patient management, but that, depending upon the circumstances, it will display information on demand to answer pertinent patient management questions, for example, to predict the consequences of trial therapy. In this sense, the computer system could be a much more useful tool than merely a monitoring device.

Such a system would also be used in education and training. In the Regional Medical Programs (RMP), the physiological monitoring emphasis appears to be primarily on coronary care training programs. The RMP lists about 57 such projects in their November 1968 Directory of Programs. This number also includes studies for feasibility of remote facilities and curriculum planning for coronary care training programs. Funds for these projects are allocated to the Region and are listed in two categories: 1) planning grants and 2) operational grants, of which the latter support the coronary care training programs.

There are nine projects, Myocardial Infarction Research Units (MIRU), being funded by the National Heart Institute at an estimated expenditure of $9,100,000 some of which may include sub-projects in physiological monitoring. Excluding the funds for the Myocardial Infarction Research Units and money spent by the Regional Medical Program on planning and training activities, the total PHS expenditure for this category is $6,508,161 [54-60].

Total Hospital Information System

Using the definition given in this Paper, there are in the United States several projects under this category. However, an operating *total* hospital information system does not now exist. Projects discussed in this category are dedicated to developing such a system; some of them have operating sub-systems, while others do not. Other agencies of the Federal government (for example, the Air Force at Brooks Air Force Base [26], and the Veterans Administration in Washington [25]) support similar programs. The projects discussed below are PHS programs.

A project entitled *Data Automation Research and Experimentation*[*] proposed an investigation, through analytical and experimental means, of methods for recording and communicating information in a modern, short-term, general hospital. The focus was on the body of information relating to an individual patient. During the period the project was supported by the PHS, both the systems analysis and the design of the system were accomplished. Implementation and operation of the system were discussed in the final report to the PHS as a continuing goal of the hospital. According to the final report, a Control Data Corporation 3300 system with an optical scanner has been selected (and contracted for purchase) by the hospital to implement the system designed.

The project *Demonstration of a Hospital Data Management System*[†] proposes to establish and operate a hospital data management system. It also proposes to 1) demonstrate the interaction between the doctor's orders and patient care, 2) demonstrate the responses of the patient to those care procedures, and 3) evaluate performance and cost usage of institutional resources. This project is in its third year, a critical one during which testing and evaluation will occur. This is a small, 54-bed hospital. It will use

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[†] William A. Spencer, M.D., Texas Institute for Rehabilitation and Research, Houston, Texas.

the Baylor University Computer facility that has an IBM 360/50 and will include video-character display terminals.

The purpose of the *Hospital Computer Project** is to 1) explore the information processing requirements of the urban general hospital, and 2) define and develop a hospital information system to meet these requirements. Certain well-specified, well-defined, modular information processing activities will be implemented on an operational, hospital-wide basis on one computer system. The major objective will be to gain experience in providing reliable, efficient, continuous service under conditions of actual use. Further, another large multi-access computer system is planned that will be used entirely for research and development, exploring modes of interaction, terminal devices, and information processing algorithms suited to a variety of situations. Among these are the use of conversational interaction techniques for the input and communication of physicians orders, the direct entry of histories, physical examinations, progress notes, and diagnostic reports, and the inquiry and generation of reports and specific information. This is a 1000-bed teaching hospital planning to implement operations in a step-wise, modular fashion--giving considerable attention to ascertaining education requirements, the problems of implementation, and the relative cost/value effectiveness. The computers to be used are the PDP-9 and IBM 360/50.

In *Demonstration of a Shared Hospital Information System*,† the hospital group will demonstrate the use of a centrally-located, shared computer for handling data for a scattered group of hospitals. The computer is used as both a switching device and a data pool to solve such urgent problems

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*G. Octo Barnett, Massachusetts General Hospital, Boston.

†Walter S. Huff, Jr., Sisters of Third Order of St. Francis, Peoria, Illinois.

as mounting clerical work load, poor communications between departments, and poor information responses of ancillary departments. Ten hospitals, ranging in size from 65 beds to 700 beds, share one computer, an IBM 360/50 with programmed keyboard terminals.

The system developing under *Computer Technics in Patient Care*[*] also uses a patient-centered approach. A patient profile is developed and the doctor's order serves as a basis for coordinating the hospital services communication system. Eventually, it is planned to integrate the financial and administrative systems that are being developed with the automated patient-care system. An evaluation of these systems and the cost will be compared to the manual system of communication for hospital care. This system is in use in a pilot 80-bed unit of the City of Memphis Hospitals. An IBM 360/40 with programmed keyboards is the computer system in use here.

Computer Facilitation of Psychiatric In-Patient Care.[†] The hospital concerned plans to develop a communication system that will serve as a prototype for State, City, and Federal psychiatric hospitals in-patient care. The standardization of behavioral observations is being used as the basis for development of the medical record. An automated nursing note has been developed. Development of the basic algorithms for classification of patients, diagnosis, prognosis, and therapy continues. This hospital has 400 beds. The computer in use is an IBM 1440 with Bunker Ramo video terminals.

The purpose of *Psychiatric Data Automation*[‡] was to develop a hospital information system based on the existing

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[*] Glenn H. Clark, University of Tennessee School of Medicine, Memphis.

[†] Bernard C. Glueck, Jr., Institute of Living, Hartford, Connecticut.

[‡] Robert E. Graetz, Camarillo State Hospital, Camarillo, California.

data-handling techniques of that hospital. A demonstration of the experimental record system paralleling the manual record system was carried out on the special experimental patient-care unit. The computer system used was an IBM 1440. This is a large State psychiatric hospital having around 4500 patients.

An eighth project funded by the Government is the one at the Veterans Administration Hospital in Washington, D.C. (Pilot AHIS) [25]. The Veterans Administration has been a pioneer in this field, having begun at Wadsworth VA Hospital in California in the early 1960s. The project was transferred to Washington, D.C. in the Fall of 1964. The objectives of the Pilot AHIS are to design, develop, test, install, and operate an experimental hospital information system. Following experience with the initial system, they plan to complete the detailed design of an integrated system. Eleven sub-systems are being developed; two of these, the Admissions and Dispositions and Radiology, are currently being tested and evaluated on all nursing units.

Three projects considered more relevant to this category than to the other five categories are:

Computer-Based Medical Interviewing Project (Warner Slack, University of Wisconsin);

Development and Use of Automated Nurse Notes (Rita F. Stein, Indiana University);

Hospital Information Systems, Optical Input/Output (Recording, Raymon Garrett, Tulane University, New Orleans).

In summary, the PHS has spent approximately ten million dollars in recent years in this category. The operating system goal is evidently quite difficult, but, as was discussed earlier, we are in a transition period. With improving hardware and accumulating software, it appears inevitable that adequate data systems can be developed at an acceptable price. These systems will then form the basis for extention into the more sophisticated uses of an information system.

In closing, we should mention the significant industrial activity directed toward design of total HIS. Inevitably, there will be omissions in this list, we list here only those which forcibly come to our attention:

1) The Bolt, Beranek and Newman system was developed in conjunction with Massachusetts General Hospital. Its extensions are continuing both at BBN and at Massachusetts General Hospital where the project of Octo Barnett (see above) is progressing.
2) The several systems developed by the Systems Development Corporation have been tested, among other places, in Puerto Rico and at Mayo Clinic, Rochester. An active group continues this development at SDC.
3) The TRW Corporation has developed an automated system in conjunction with the University Medical School, Toronto, and elsewhere. Details of this system are not immediately available.
4) The Lockheed Corporation has developed an extensive system and has several field tests and installations in operation. In addition, Lockheed contracted with the PHS to, briefly, analyze and report on the hospital information system problem. Among other results in this report, the information flow lines in a typical hospital were plotted and an algebra was developed to describe information flow quantitatively. A method was also designed to evaluate an arbitrary HIS [2].
5) The IBM project with the Monmouth Medical Center, Monmouth, New Jersey, is representative of the many projects by IBM in both total HIS and in numerous sub-systems for this application.

6) A project at the Beaumont (Texas) Baptist Hospital is applying a system called REACH (Real-time Electronic Access Communications for Hospitals) designed by the National Data Communications Corporation. In this system, patient records, bed census, drug files, medical records, business office transactions, and other records and data are entered and displayed on CRT consoles located throughout the hospital. Most of the system is now operational with a duplicated (small) central computer and 36 consoles in the first demonstration system.

7) Arthur D. Little Corporation, the MITRE Corporation, The RAND Corporation, and others are also involved at various levels in the development of hospital information systems.

V. CONCLUSIONS

We believe a number of conclusions can be gleaned from the foregoing material.

Table 3 summarizes PHS expenditures for the several HIS categories.

Table 3

TOTAL GRANT AND CONTRACT MONEY SPENT AND OBLIGATED FOR HOSPITAL INFORMATION SYSTEM BY THE PUBLIC HEALTH SERVICE

Total	$32 Million
Diagnostic Laboratory	15.6 percent
Physiologic Monitoring	20.5 percent
Logistics	13.3 percent
Medical Records	13.3 percent
Total HIS	31.4 percent
Other	5.9 percent

Although a considerable amount of money has been spent on attempts to develop a total hospital information system, the amount of money invested to date has not been excessive in view of the complexity of the task.

At present, there is no fully functioning total hospital information system and, with one or two exceptions, such systems are not even employed on a piecemeal basis in the delivery of medical care. To the extent that any success has been achieved, it has been only in those instances where institutions and/or investigators have implemented a relatively limited set of objectives.

Although attempts to develop a total health information system have been quite disappointing, there has nevertheless been some rather remarkable success in at least two areas: 1) the automation of the business functions of hospitals, and 2) the automation of clinical chemistry laboratory procedures.

It seems noteworthy that so many hospitals throughout the country have chosen to spend their *own* funds to install computer systems to automate business procedures and, to a somewhat lesser extent, clinical chemistry laboratories. It is obvious that in both these instances large sums of money have been spent without government subsidy; more than anything else, this illustrates that in these two areas cost-benefit must have been recognized and achieved.

The discrepancy between the apparent success and enthusiasm for the computer in the business office and laboratory as opposed to patient management suggests that in these areas the need for the computer was more easily recognized. There was a strong motivation to see these projects through to a successful operational stage. Thus, it may be that the lack of success in other areas has resulted from an inability of hospital administration to precisely define either the need for or usefulness of the computer in patient management. We would speculate that until other medical services, independent of external pressures, are capable of recognizing and demanding more efficient utilization of their time and services, attempts to automate these activities will continue to fail.

We recognize that the modern hospital is in fact not a single homogeneous activity but rather a conglomeration of activities that, from a functional view, are only minimally related. It is reasonable, therefore, that the needs for increased efficiency as well as the recognition of these needs will develop at different rates. This differential awareness probably mitigates very heavily against the development of a total comprehensive nospital information system.

We believe that there are certain technological considerations that bear on the above observations. First, ignoring some of the organizational constraints to which we have alluded, it is quite possible that the failure of computer time-sharing to develop on the schedules originally projected by our information scientists contributed in some way to the failures of many of the systems attempted. Quite simply, the technology was not equipped to provide simultaneously for the many divergent and data-rich requirements of the multitude of services that exist in any relatively large hospital. More importantly, however, is the possibility that what was technologically required was the development of a computer system adaptable to an unevenly evolving need for computers among the several services in the hospital, rather than to a total frontal attack on all hospital services. The ultimate solution to the hospital information problem may not be the development of more useable time-sharing systems, but rather the development of a capability that can tie together discrete information-handling capabilities as they develop at their own speed within the several hospital services. Therefore, we submit that at least one possible solution to the organizational problem, which seems to be the crux, is to find some way to bring many discrete activities together as they occur at their own rate of development. In this sense, the notion of networking computers, especially computers not immediately compatible with one another, may have a great deal more potential for the evolution of a hospital information system than an attempt to solve the problem with one very large machine. This very general suggestion obviously needs a great deal more study, but we believe that it has the virtue of adapting itself to reality, rather than trying to impose upon the hospital an organizational structure completely out of phase with the way hospital functions are traditionally performed. It can be argued that what is needed is a total revolution in the organization of our hospitals, but this is much less likely to be achieved in the near future than a solution that adapts itself to the way things actually are.

It is our opinion that, although every opportunity should be taken to explore and examine new ideas and opportunities in an attempt to develop hospital information systems, a great deal of caution must be exercised in sponsoring activities that do not appear to have the minimum ingredients for success. We do not believe that we have identified all of these by any means; but we feel that past efforts give us certain insights and experience that begin to suggest certain minimal conditions, as well as new and as yet untried technological directions.

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